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α - Particle and NBI - Ion Deposition in a Compact Spherical Tokamak due to Slowing Down.

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Abstract. Codes NFREYA and TORUS II are used to calculate the α – particle containment and loading as well as the power deposition and the driven current in ST40 high field spherical tokamak. First orbit approximation and complete slowing down orbits, needing 6.25 10^7 computed orbit points approximately, were used. We show that for ST40 conditions, the containment depends mainly on the peaking parameter of the density profile (p~2) which can be reached by the pellet injection. The maximum containment in the case of slowing down orbits is around 0.25 agreeing roughly with the first orbit guiding center calculations.

1. Introduction

The new generation high field spherical tokamak ST40 (R_0=0.4m, A=1.6, I_{pl}=2 MA, B_t=3 T, k=2.5) is under construction by Tokamak Energy Ltd, UK. The heating, the current drive and the torque, produced by the Neutral Beam Injection (NBI), the resulting plasma rotation and bootstrap current, had been investigated with the Monte Carlo (M-C) code NFREYA, and the 1.5d-transport code TORUS II /1,2,3/. NBI heating (P_b=1MW, E_b=40-70keV) and density build up by pellet injection /4/ generate burning plasma conditions. The containment, the power deposition into electrons and ions of the released α - particles as well as the loading of the first wall are investigated here by solving the Fokker – Planck equation. In contrast to the first orbit approximations /5/ the computed α - particles orbits can change their topology because of the collisions during slowing down /6/, in particular at small pitch angles.

2.Generation and slowing down of the α - particles

Since the α – particle generation profile n_t n_d $<\sigma_f v>$ depends (at constant temperature) strongly on the density, the dependence of the containment and the loading of the first wall on (n_t n_d) is investigated. For density profiles we assume $n_t = n_d = n_0 f(\rho)$ with $f(\rho)=(1-(\rho/a)^2)^p$. The peaking parameter p produces flat profiles for p<1 and and a peaking at ρ=0 for p>1. For temperature profiles we assume $T_{i.e}=T_{i0,e0}(1-(\rho/a)^2)$. Pellet injection is used to adjust the parameter p. The pellet ablation model is that of Houlberg – Milora - Foster using multiple energy groups to account for the maxwellian background plasma /4/. Since the α -

particle energy E_α=3.5 MeV is 50-100 times larger than the beam energy E_b=35-70keV, the tracklength for slowing down increases from 20 km to roughly 2000 km in the guiding center approximation thus increasing strongly the necessary computer time. We note that the slowing down time τ_s /6/ does not depend on E_α.

3. Results

Table 1 shows results of calculations of the guiding center slowing down. The slowing down length of roughly 2000 km corresponds to ~2 10^6 /(2π R q)≈2 10^5 'elementary orbits' encircling the magnetic axis. Since 80 of these orbits (co – or counter-orbits like in the first orbit approximation) contain 25000 computed orbit points, around 6 10^7 orbit points must be computed for slowing down of one M-C particle. This is very large compared with the ~300 points for the first orbits. However, only the slowing down calculations allow to account for the main physics such as power deposition on electrons and ions and the losses to the first wall.

Table 1

Guiding center slowing down				
P	0.125	0.25	0.5	0.75
Power cont.	0.22	0.25	0.27	0.24
P	1	2	4	10
Power cont.	0.273	0.265	0.272	0.23

The peaking parameter is chosen to produce flat density profiles ($0.125<p<1$) and peaked profiles ($1<p<10$). Despite of the statistical error in Table 1 an increase of the containment by around 22% can be seen at p=2. The analogous calculations for the first orbit calculations give 60% increase in the case of the guiding center approximation and 14% in the case of the full orbit calculations thus confirming the improvement due to peaking of the profile qualitatively. Fig.1 shows a counter running particle, encircling the left stagnation point with a large negative pitch. Due to the reduction of the speed the particle moves to the outside and is lost prior to complete the slowing down. Figs. 2 and 3 show changes in the orbit topology mainly due to the pitch angle scattering. In Fig. 2, left, the particle starts as co-particle, a sequence of bananas occurs due to the reduction of the pitch angle and then it is scattered into a co-running orbit which contracts around the right stagnation point. Similarly, in Fig. 2, right, the particle starts with the co-leg of a banana. After some banana orbits a sequence of co-running orbits appear contracting around the right stagnation point. In Fig. 3 the case of a particle slowing down by banana orbits is shown. The co–legs of the bananas try to move toward the right stagnation point and the counter-legs move away from the left stagnation point. The particle is then slowed down in a sequence of almost stationary bananas at the boundary. Fig. 4 shows the loading of the wall decomposed in 16 surface elements /2/. The total loading is 577 kW and the peak loading is 200kW/m^2 (element 7). With increasing elongation (κ=3) the containment decreases by 8%, and the total loading increases by 6%. The peak loading doubles because of the orbit changes. The time evolution of the electron density with repetitive pellet injection is shown in Fig. 6. The pellet radius is 0.4 mm, the repetition time is 100 ms. In the average the profiles become approximately triangular corresponding to p≈2. The ion temperature evolution can be seen in Fig. 5. Here the peaking is more pronounced thus increasing the generation of α-particles at the plasma center.

4. Conclusions

First orbit calculations show an increase of the containment with the peaking parameter, 60% in the case of the guiding center, 14% in the case of full orbit calculations. This tendency is confirmed by slowing down calculations showing an increase by 22% if the peaking parameter increases to p~2; this and the appropriate temperature profiles (Fig. 6) can be reached with NBI (E_b = 40 keV) and repetitive pellet injection (PEP discharges).

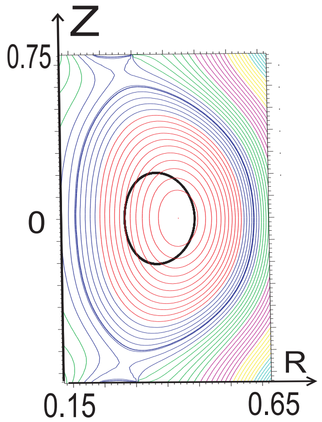

Fig.1 Counter running α particle

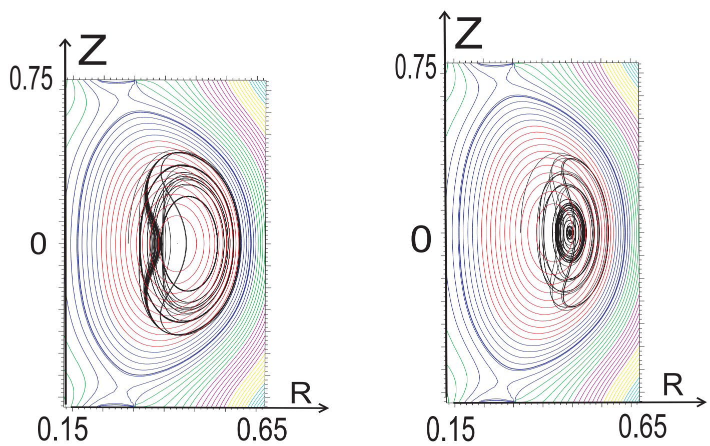

Fig.2 Changes of orbit topology, co- to banana (left) and banana to co – particle (right)

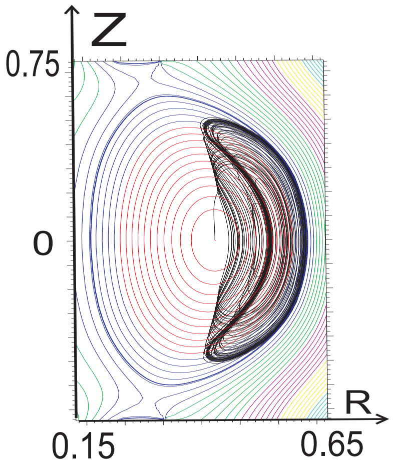

Fig.3 Evolution of banana orbits

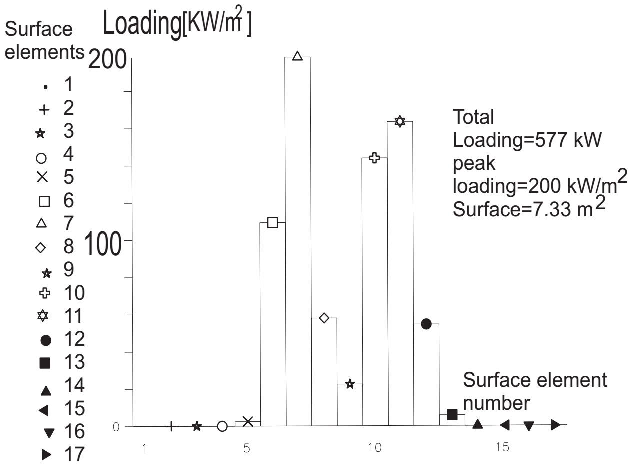

Fig.4 Loading of the first wall

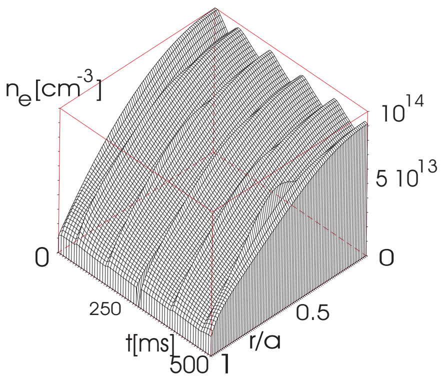

Fig.5 Time evolution of the density N_e with repetitive pellet injection

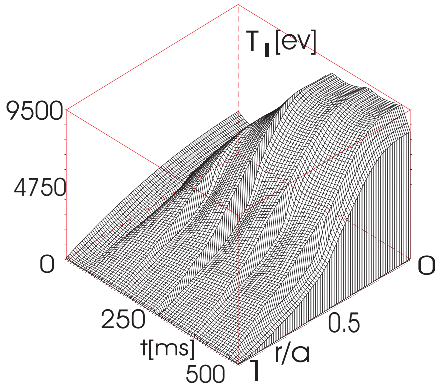

Fig.6 Time evolution of the ion temperature with repetitive pellet injection

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